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The influence of the escaping device on the hydrodynamics of submerged floating tunnels under flow

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Abstract

A potential approach to settle the problem how to survive major safety accidents in submerged floating tunnel (SFT) is presented, i.e. a detachable escaping device. The CFD method is used to investigate the influence of the escaping device on the hydrodynamics of submerged floating tunnels in uniform flow and oscillatory flow. The Navier-Stokes equations and standard turbulence equations are solved by finite volume method (FVM). GAMBIT is used as the pre-processor and Fluent is used as the solver. In uniform flow, the escaping device reduces the drag force of SFT by more than thirty percent. In oscillatory flow, the escaping device has little influence on hydrodynamics of SFT.

Keywords: submerged floating tunnel; escaping device; hydrodynamics; flow

1. Introduction

The submerged floating tunnel (SFT or Archimedes bridge) is an innovative concept for crossing waterways. The tube of SFT is floating in the water due to positive net buoyancy, at some convenient depth, and fixed to the seabed by means of a suitable anchoring system, such as cables or bars. A first realization of an SFT is still missing. This is a great challenge to engineering science community and has attracted preliminary investigations [1–7].

There hasn't been a built submerged floating tunnel (SFT) in worldwide, for which the safety problem of SFT is one of essential factors. When safety incidents occur, it is important to quickly and safely escape from the scene of accidents. At present, there isn't still an effective means to settle the problem of safely escaping when serious safety accident takes place. We present a potential approach to settle the problem that separable escaping device is set outside SFT. Separable escaping device is connected together with SFT in operation and can depart from SFT after passengers enter it in an emergency situation. It goes up to the water surface due to buoyancy force. Separable escaping device is a new concept on the safety escaping system of SFT and presents an implementationable

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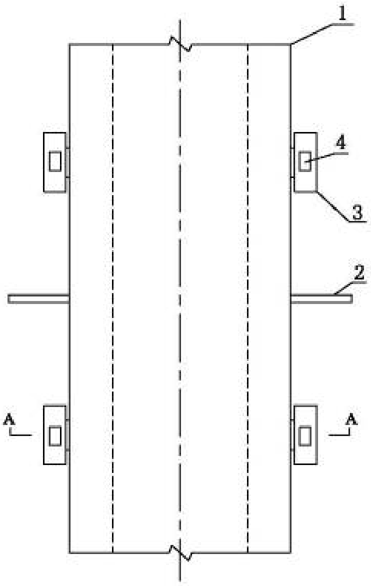
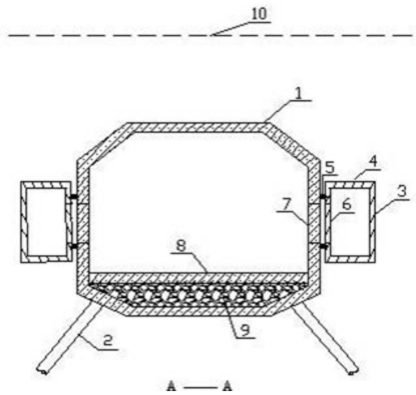
possibility of the safety escaping system of SFT. In the study, the method of the secondary development based on FLUENT is used to investigate the influence of escaping device on the hydrodynamics of SFT in flow environments.

2. Concept design on the escaping device

For the problem how passengers escape safely from SFT in an emergency situation, Dong et al. [8] designed a detachable escaping device set outside SFT, referring to Fig. 1. When a major safety accident takes place, one can enter a nearby escaping device by means of two safety exits which are closed at the usual time. The escaping device goes up to the water surface due to buoyancy after it is detached from the tube. One can escape from the scene of the accident through upper exit of the escaping device. The way could save a lot of time as compared with the traditional methods, as well as magnify safety factor of surviving the accident.



(a) Vertical view



(b) Cross-section view

Fig. 1. Vertical view of schematic diagram of submerged floating tunnels with the escaping device: 1 tunnel tube, 2 mooring system, 3 escaping device, 4 upper exit of escaping device, 5 separable connection between the tube and escaping device, 6 safety exit leading to the tube, 7 emergency exit leading to escaping device, 8 pavement, 9 subgrade, 10 water surface

3. Model and computational methods

3.1. Mathematical model

It is assumed that the fluid is incompressible. The incompressible Navier-Stokes equations are expressed as

$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla)\mathbf{u} - \frac{1}{Re}\Delta \mathbf{u} + \nabla p = 0 \tag{1}$$

where $\mathbf{u}$ and p denote the unknown flow velocities and pressure, respectively, and Re is Reynolds number of the flow.

Continuity equation reads

$$\nabla \cdot \mathbf{u} = 0 \tag{2}$$

The standard $k-\varepsilon$ turbulence equations reads

$$\rho \frac{\partial k}{\partial t} + \rho(\mathbf{u} \cdot \nabla) k = \nabla\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\nabla k\right] + G - \rho\varepsilon \tag{3}$$

$$\rho \frac{\partial \varepsilon}{\partial t} + \rho(\mathbf{u} \cdot \nabla) k = \nabla\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\nabla \varepsilon\right] + C_{1\varepsilon}\frac{\varepsilon}{k}\left(G_k + C_{3\varepsilon}G_b\right) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} \tag{4}$$

where k is the turbulent motion kinetic energy, ε is the turbulent kinetic energy dissipation rate, G is the turbulent generating term, μ_t is the turbulent viscosity coefficient. $C_{1\varepsilon}, C_{2\varepsilon}, C_{3\varepsilon}$, σ_k and σ_ε are the empirical constants, and their usual values are given in the following Table 1:

Table 1. Value of empirical constant

Coefficient	Value
$C_{1\varepsilon}$	1.44
$C_{2\varepsilon}$	1.92
$C_{3\varepsilon}$	0.09
σ_k	1.00
σ_ε	1.30

3.2. Physical model

We shall simplify concept design model of SFT as 2-D model so that it is convenient to analyze theoretically its hydrodynamical properties. The outline of SFT with escaping devices is showed by Fig. 2. SFT is of axial symmetry with respect to the horizontal and vertical axises, respectively. The height and the width of SFT is 760cm and 1600cm, respectively. The dimension of cross-section of escaping device is 300cm×300cm.

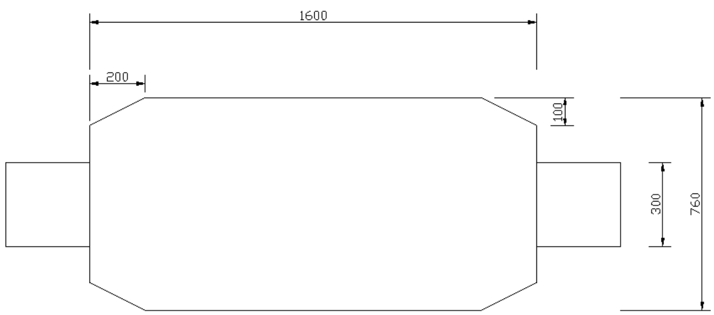


Fig. 2. 2-D schematic diagram of submerged floating tunnels with the escaping device

The geometrical model of SFT is created using Fluent's Gambit pre-processing tool and the mesh is generated in Gambit, referring to Figs. 3 and 4.

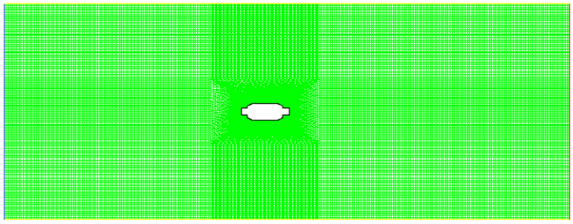


Fig. 3. Schematic of the grid of submerged floating tunnels with the escaping device

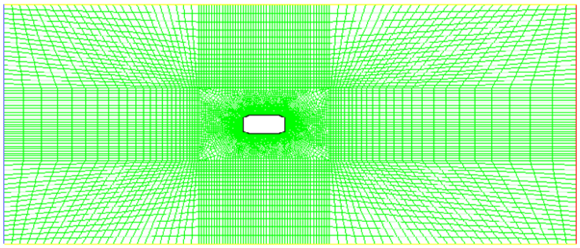


Fig. 4. Schematic of the grid of submerged floating tunnels

3.3. Boundary conditions

On the rigid wall of submerged floating tunnel, Γ_S , the slip boundary condition is imposed

$$\mathbf{u}|_{\Gamma_S} = 0 \tag{5}$$

The left boundary condition of the computational domain is set as velocity inlet, and the right boundary is set as outflow. The upper boundary is velocity inlet for uniform flow and symmetry for oscillatory flow. The lower boundary is velocity inlet for uniform flow and symmetry for oscillatory flow.

3.4. Numerical algorithm

The Navier-Stokes relations Eq. (1) are solved together with Eqs. (2), (3) and (4) using the FVM. Here some details about our own implementation of the method are given. Velocity and pressure fields are coupled with SIMPLEC algorithm to discretize the governing equations. The discretization methods of turbulent kinetic energy and dissipation rate are selected as first-order wind scheme. Turbulent intensity is one percent. Hydraulic diameter is one meter.

4. Numerical results and discussion

4.1. The influence on hydrodynamics of SFT in uniform flow

It is assumed that the structure of SFT is stationary when analyzed. Fig. 5 shows that the rate of the drag force of SFT with escaping devices to without them varies with flow velocity. Velocities of uniform flow are 0.4, 0.6, 0.8, 1.0, 1.2 and 1.4m/s when analyzed.

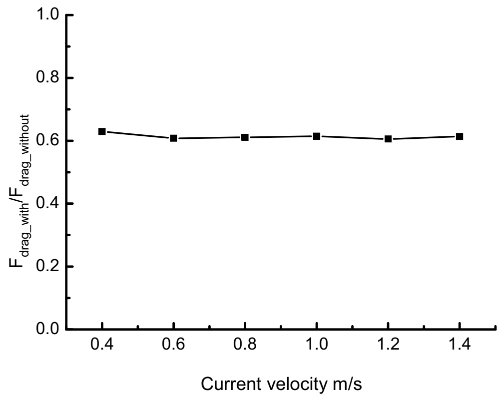
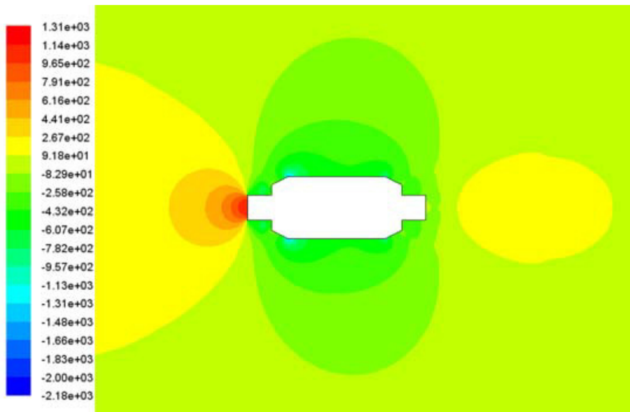
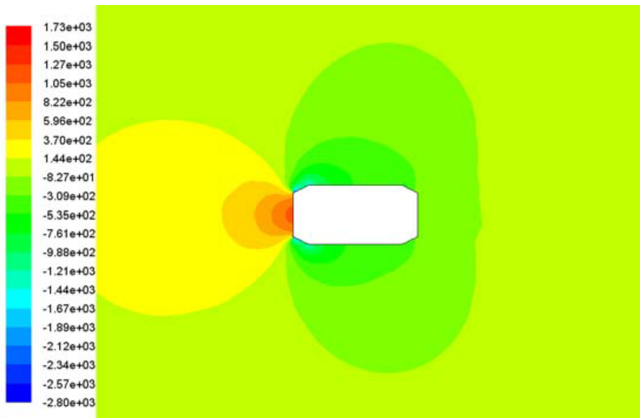


Fig. 5. Schematic of the relationship between the rate of F_{drag_with} to $F_{drag\_without}$ and current velocity

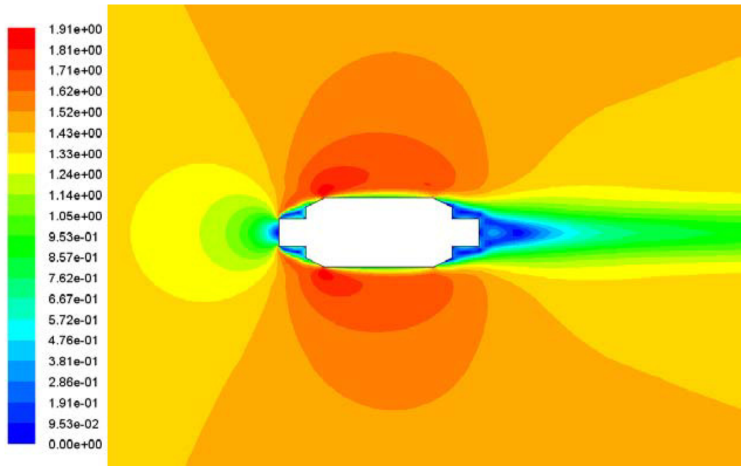


(a) SFT with escaping devices

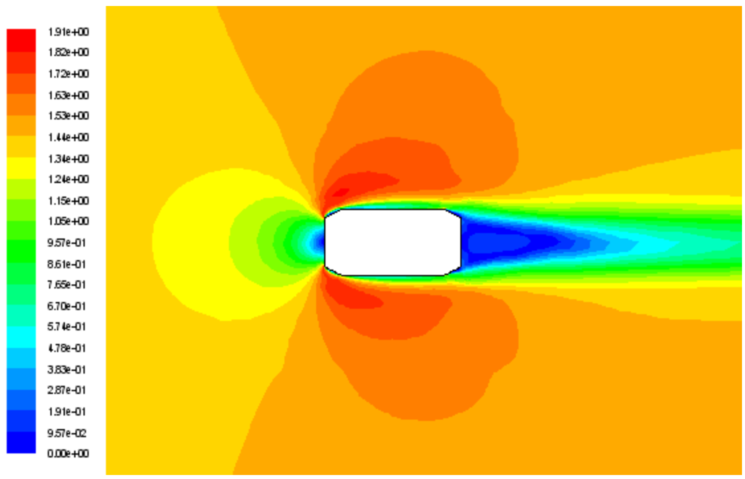


(b) SFT without escaping devices

Fig. 6. Contours of pressure when v=1.4



(a) SFT with escaping devices



(b) SFT without escaping devices

Fig. 7. Contours of velocity magnitude when v=1.4

Fig. 5 indicates that the rate of $F_{\text{drag\_with}}$ to $F_{\text{drag\_without}}$ is between 0.6 and 0.65. According to Figs. 6 and 7, the existing of escaping devices change the outline of SFT, and make it close to streamline. So escaping devices can reduce noticeably the drag force applied to SFT.

4.2. The influence on hydrodynamics of SFT in oscillatory flow

The amplitude of oscillatory flow is 1.4 m/s. The period of oscillatory flow is 20 second. Time step size is 0.005 s. The drag force applied to SFT during a period refers to Fig. 8. Fig. 8 shows that the escaping devices have little influence on hydrodynamics of SFT so that the change of the drag force caused by them could be ignored in design.

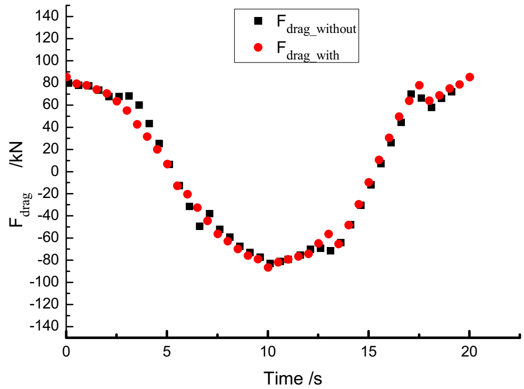


Fig. 8. The drag force applied to SFT during a period

5. Conclusions

An innovative way to escape from submerged floating tunnel in an emergency situation, i.e. detachable escaping device, is presented. The CFD method is used to investigate the influence of the escaping device on the hydrodynamics of submerged floating tunnels in uniform flow and oscillatory flow. In uniform flow, the existing of escaping devices changes the outline of SFT, and makes it close to streamline. The escaping devices can reduce noticeably the drag force applied to SFT. While, in oscillatory flow, they have little influence on hydrodynamics of SFT, and the change of the drag force caused by escaping devices could be ignored in design.

Acknowledgements

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